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A VISUAL APPROACH AND LANDING SIMULATOR SYSTEM

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THESIS

A VISUAL APPROACH AND LANDING SIMULATOR SYSTEM

by

James Nicholas Kraft

Thesis Advisor: D. M. Layton

September 1971

Approved for public release; distribution unlimited.

A Visual Approach and Landing Simulator System

by

James Nicholas Kraft
Lieutenant, United States Navy
B.S., United States Naval Academy, 1964

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1971

ABSTRACT

An F-105 Canopy/Seat Cockpit Trainer, Panasonic Television Monitor System, and an SMK-22 Visual Approach Simulator were interfaced to yield a low-cost, six-degree-of-freedom visual approach and landing simulation system for future research and classroom use. Stick and throttle outputs from the cockpit were made to operate all six degrees of freedom. The television monitor was mounted forward of the cockpit instrument panel to provide visual cues for approaches, landings, and take-offs. Cockpit instruments consist of airspeed, altimeter, and ID-249 ILS indicators.

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I. INTRODUCTION

With the exception of catapult launches from aircraft carriers and actual combat, the most dangerous phase of fixed-wing aircraft operations occurs during approaches and landings. Continued research concerning the approach and landing phases of flight could yield valuable information to reduce the danger involved in these operations and perhaps provide new techniques or aids to assure that landings and take-offs would correlate at a nearly one-to-one ratio.

Much research is presently being done by the Navy concerning carrier landings. Every carrier landing attempt is graded by a Landing Signal Officer (LSO). On several ships these approaches to landings are also recorded from radar returns of altitude, airspeed, and glide slope tracking. All these data are forwarded periodically to the Navy Safety Center at Norfolk, Virginia for correlation.

Studies such as just described are quite expensive. Less expensive research could be carried out using instrument simulators, i.e., simulators in which the pilot receives visual cues from instruments alone. These simulators, however, have several drawbacks. The pilot can readily perceive only three degrees of freedom: yaw, roll, and pitch. Altitude and forward and lateral motion are only available through correct interpretation of

several instruments. Furthermore, the landings made using only the instruments do not occur in reality. During every landing there must be some outside visual reference available.

The object of this project, therefore, is to provide a low cost platform for future use in approach and landing research. This system is to have a visual presentation in the cockpit to provide the pilot with all six degrees of freedom, including the three degrees that are missing in standard instrument simulators, namely: forward, lateral, and vertical motions.

II. DISCUSSION

A. BACKGROUND

The initial attempt to build this visual approach system consisted of a tripod mounted television camera. A motor drive on the tripod provided motion in the pitch and yaw senses. Forward motion was provided through the use of a zoom lens.

This attempt proved to be unsatisfactory. There was no method of controlling lateral or vertical motion of the camera. Thus, no matter how the camera was yawed or pitched, it was always on centerline and on the same glide-slope angle relative to the landing area.

In order to be able to focus on the landing area, a fairly large model (32 inch, 600:1 scale wood carrier deck) had to be used. This decreased the zoom range to less than one quarter mile and the camera could not be zoomed to a touchdown position.

Finally, the camera could not be banked. This feature alone would destroy the realism of the system to rated pilots.

Consultation with the Flight Simulation Branch at NASA's Ames Research Center, Mountain View, California lead to the acquisition of a surplus SMK-22 Visual Approach Simulator from Hill Air Force Base, Salt Lake City, Utah. This simulator provided the six degrees of freedom necessary for an acceptable system.

B. SMK-22

The SMK-22 visual simulator (Figure 1) represents the linear perspective of a simulated airfield so that one can practice night approaches, take-offs, and landings under various visibility conditions. It was originally designed for integral use with B-52, C-118, P-3A, C-11, and other standard Navy and Air Force flight simulators.

The pilot's view from an aircraft is simulated by a television camera with the same degrees of freedom as an aircraft in flight: azimuth (yaw), bank (roll), pitch, and lateral and vertical motion. The appearance of forward motion is produced by moving a simulated runway under the camera. This visual information is then presented on a cockpit monitor.

A 10,000 foot long, 170 foot wide runway is represented by a 600:1 scale thirty foot endless belt with phosphor coated beads and runway markers bonded permanently to its surface. A 3,000 foot strip of approach lighting is provided (Figure 2). Ground speeds of zero to 250 knots can be simulated by varying the belt driving motor speed.

Lighting arrangements similar to that of an actual airfield are used for reference during landing operations. The distant flashing of the high intensity strobe light is the first visual cue to the pilot when approaching a runway under low visibility conditions. This effect is simulated by a perceptual strobe light mounted on the main attachment above the far end of the runway belt. Two small illuminated

plastic rod ends above the belt flash in sequence to give the same appearance on the monitor as the strobe lights seen from a distance. This extends the visible range of the trainer to one mile. The perceptual strobe is synchronized with the main strobe lights and fades out as the latter come into view.

The strobe lamp is a fluorescent lamp under the belt. There is a metal shield around this lamp, with a thin transparent spiral in it, like a barber pole. The only illumination to the under side of the belt is through the transparent spiral. The shield is rotated around the lamp by the strobe motor. As the shield rotates, a thin beam of light through the spiral will seem to move down the center of the belt, away from the camera. Little plastic rod ends, embedded in the belt to simulate the strobe lights, go completely through the belt. They light up when hit by the moving beam of light from below the belt and the light reflected by them is picked up by the camera. Since the beam of light moves down the belt, the strobe lights appear to flash in sequence.

Conditions of poor visibility are simulated by passing a motor driven visibility filter along the belt, between runway and camera so that the lights in the background are more or less obscured.

Landing lights, controlled by a switch in the cockpit, are mounted on either side of the camera.

During the approach phase, the belt position, height above the runway, and lateral distance are compared to a

three-degree glide slope and on-centerline signal to provide direct inputs to the horizontal and vertical needles of an ID-249 ILS indicator in the cockpit.

Input signals for positioning the belt and camera come from the cockpit. Basically, the visual simulator is an analog computer, employing various servomechanisms for velocity and position information and operational stability.

Velocity signals are used to drive the belt and the camera lateral drive. Operation in a velocity mode eliminates errors ordinarily resulting from low resolution potentiometers, which could cause irregular servo operation as the brush traveled over individual turns of wire.

The relative coordinate velocities are termed $\dot{X}$LAS and $\dot{Y}$LAS. XLAS is the aircraft groundspeed along a line parallel to the extended runway centerline. $\dot{Y}$LAS is the aircraft groundspeed at right angles to the centerline. Both of these groundspeeds are independent of aircraft position. When the aircraft is moving parallel to the runway, $\dot{Y}$LAS is zero. If the aircraft could fly perpendicular to the runway, $\dot{X}$LAS would be zero. In any other motion, $\dot{X}$LAS and $\dot{Y}$LAS will be the vector components of the aircraft's velocity. Velocities up to 250 knots can be simulated. The maximum lateral simulated distance from the centerline is 450 feet right or left.

The vertical drive is always operated as a position servo. The limits of simulated vertical travel are from zero to six hundred feet above the runway.

The attitude servos position the camera to simulate the heading, bank, and pitch of the aircraft. The three degrees of freedom are provided by a gimbal system (Figure 3) that pivots about a point directly behind the camera lens. Since the principal point (entrance pupil) of the camera corresponds to the pilot's eyes, the point of rotation is placed behind the lens to represent the aircraft center of gravity. The limits of bank and heading are plus and minus thirty degrees. Those for pitch are plus and minus fifteen degrees.

C. MODIFICATIONS

As previously stated, the SMK device was designed to receive inputs directly from various cockpit simulators. These inputs included the aircraft's horizontal and lateral distances from the runway, heading, altitude, field elevation, barometric pressure, airspeed, and wind components, to name but a few. If one were to construct a system with all these outputs, he would merely duplicate an expensive simulator.

Inputs to drive the simulator were kept to a minimum of three: airspeed, roll, and pitch.

The airspeed signal from the cockpit was connected to the XLAS input of the simulator. This signal is actually a groundspeed or no wind airspeed signal that comes directly from the throttle in the cockpit. There is no connection between airspeed and pitch angle in this setup. Phugoid airspeed changes were neglected. Since many small corrections

are usually made during an approach, the phugoid oscillations have little chance to influence the motion of the aircraft. The inertia of the belt provides a delay in throttle response but, to facilitate the installation of the cockpit instrumentation, displayed airspeed is derived directly from a throttle-mounted potentiometer and therefore does not have a delay.

The roll signal comes directly from the stick in the cockpit. Roll is calibrated at one degree per volt, with maxima of plus and minus thirty volts available at the stick. Physical restraints on the stick, however, limited the maximum bank to ten degrees. An artificiality was present in that the pilot had to keep the stick deflected to maintain a bank angle. This artificiality was removed by disconnecting the roll feedback so that stick deflection now controls the rate of roll. A constant bank angle can be maintained with the stick in the neutral position. The dynamics of the gimbal system and servo amplifiers create a slight delay between input and response in roll, as is the case in an actual aircraft.

There was no device readily available to transmit heading information from the cockpit to the simulator. The output from the roll position servo was used to drive the heading motor directly. Any bank angle creates a heading change rate. Higher bank angles increase the rate of heading change.

The lateral drive is operated in a similar manner. The output of the heading position feedback was connected to the YLAS input. Any heading signal not parallel to the runway produces a signal to drive the lateral drive, larger heading deviations giving higher lateral velocities.

The pitch servo is driven directly from the stick in the cockpit. Physical limits of stick travel limit the pitch motion to 8 degrees up and twelve degrees down.

It was originally thought that the pitch feedback signal could be made to drive the vertical drive motor. This was found not to be the case because of a nonlinear spring on the vertical drive mechanism.

This problem was solved through the installation of an additional motor-gear system in the simulator that was made to run from a pitch feedback signal. The gears drive a potentiometer, the output of which is connected to the altitude input of the simulator. Up and down pitch feedback signals run the motor to turn the potentiometer giving outputs from minus six to zero volts, corresponding to 600 to zero feet altitude above the runway. A zero pitch feedback signal maintains the camera at a constant altitude.

Aircraft distance from the localizer was needed to operate the horizontal needle of the ID-249 indicator. No provision was made for this in the simulator setup. The solution to this problem was found by stepping down the belt position feedback (K2 pin 12 Amp. Assy. 1) to input into the XLAS (aircraft distance from the localizer)

connection to the horizontal needle circuitry (K1 pin 19 Amp. Assy. 1).

With only a velocity signal available and no aircraft position input to the simulator, the belt could only be run, from the cockpit, in a velocity mode. The simulator will operate in this mode only if the "Within Start" relay is closed. The Velocity Track switch on the Control Console closes this relay to allow operation of the strobe lights and velocity mode operation of the belt.

The Landing Light relay was rewired so that one control wire went to ground and the other went to the Landing Light switch in the cockpit.

The Control Console (Figure 4) was constructed based on the simulator's Instructor Console wiring diagram, with the unnecessary wiring deleted. The purpose of the Control Console is to operate some of the functions of the simulator not under the pilot's control.

The lighted Emergency Power Off button provides an indication when the simulator is on. Depressing this button removes all power from the system.

The Servo-Man light indicates that at least one degree of motion of the simulator is in the manual mode.

The Freeze light indicates when the simulator is "frozen." Turning on the Freeze switch stops the belt and makes all inputs to the camera drives zero.

The Strobe switch and light controls and indicates power to the strobe lights.

The Velocity Track light and switch closes the Within Start relay to put the belt drive in a velocity mode. The belt must be in this mode for strobe light operation.

The Program Start light and spring loaded switch is used to position the aircraft on the runway for take-off.

A Visibility Adjust knob controls the position of the visibility filter over the runway.

Two extra knobs are on the Control Console for the ceiling control. This circuitry is not used but is provided for future use in manipulating a shutter on the camera to simulate a broken or lower ceiling.

D. COCKPIT

An F-105 Electric Seat/Canopy training device was used for the cockpit porition of the system (Figure 5). All the electrical circuitry was removed from the cockpit, with the exception of a convenience outlet and the power supply for operating the seat and canopy. The cockpit was interfaced with the simulator through a multiwire cable (Table II), a camera cable, and a power cord. The power cord is connected to a phase-C convenience outlet on the top of the simulator so that when the simulator is off there is no power to the cockpit or camera.

The throttle quadrant (Figure 6) came from an FJ Fury aircraft. A geared potentiometer was mounted so that motion of the throttle directly varied its output voltage. This output was connected to the belt drive velocity ($\dot{X}$LAS) input of the simulator. With a voltage range from zero to

minus thirty volts a.c., airspeeds of zero to 250 knots can be simulated.

The throttle output was also connected to a fifty volt a.c. voltmeter on the instrument panel to provide airspeed indications in the cockpit.

A spring balanced position stick (Figure 7) was obtained indirectly from the Air Force Flight Dynamics Laboratory. A potentiometer was mounted directly to each of the two stick axes. The outputs from these potentiometers are used as inputs to the roll and pitch servo amplifiers on the simulator.

The blank metal plate instrument panel was replaced with one of plastic (Figure 8). On this panel were mounted airspeed, altitude, and ID-249 ILS indicators and a landing light switch.

The airspeed indicator has previously been discussed. The altitude indicator is a thirty volt d.c. voltmeter relabelled to indicate heights above the runway from zero to 600 feet.

The ID-249ILS indicator provides azimuth and glide-slope information to the pilot in the same manner it would in an actual aircraft.

The landing light switch controls the two landing lights mounted one on either side of the camera.

Visual information is presented to the pilot by a Panasonic television monitor system. The camera is mounted on the gimbals in the simulator. A television viewer is

mounted forward of the instrument panel in the cockpit, where the pilot would normally look for the runway during an approach and landing. Another viewer is located outside of the cockpit at the Control Console. Camera power, brightness, contrast, and electronic focus are controlled from this viewer. The television system receives power from the cockpit convenience outlet.

III. RESULTS AND REMARKS

The objectives of this project were realized. This six-degree of freedom visual landing system functions very much like a real aircraft in flight.

The out-of-pocket cost of the system amounted to less than $650.00. The only items that had to be purchased were the television monitor system, ultraviolet lights, and some potentiometers.

The system is readily available for research and classroom work in the Naval Postgraduate School Aircraft Simulation Laboratory.

During construction only airspeed and altitude indicators were added to the cockpit because it was felt that all other position and attitude cues would be available from the television viewer. (The ILS indicator was used because the simulator provides the signals necessary to make it function.) The instrument panel could easily be expanded to include pitch, roll, heading, and horizontal distance information. The signals to drive these indicators could be taken from the various feedback signals.

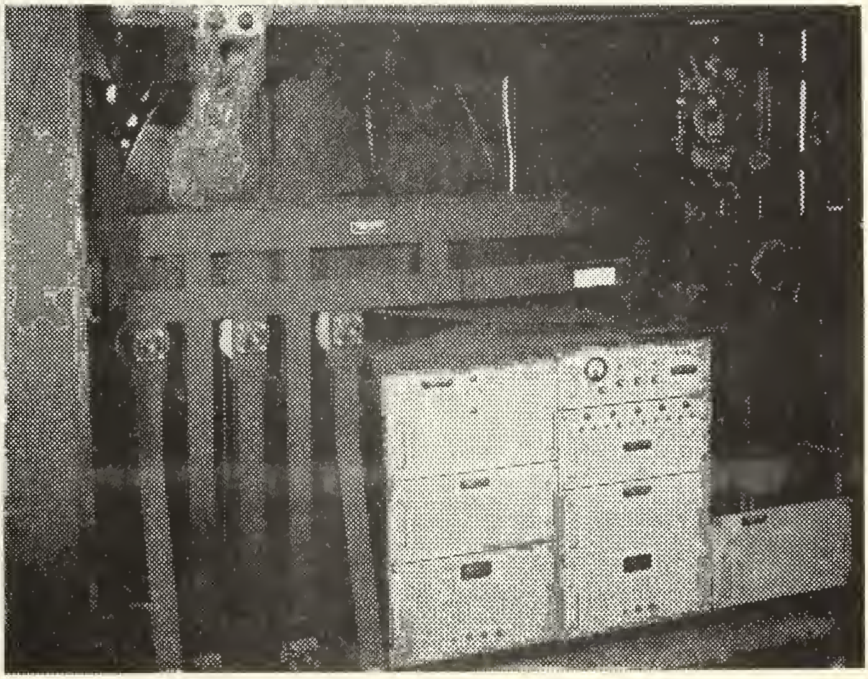
The cockpit is wired to accept a sidearm controller as well as a conventional floor-mounted stick. Both position and force stick-control research can be conducted from either position. The stability and gain of the servo amplifiers can also be adjusted.

Lower and broken ceiling conditions could, in the future, be added by passing an object in front of the camera so that the runway could not be seen above a desired altitude or would be seen intermittently, as in the case of a broken ceiling. The wiring to operate such a feature is incorporated in the Control Console.

The Panasonic monitor is capable of operating three separate cameras, and another gimbal is readily available. Thus, for a minimal added investment, the whole system could be vastly expanded. The extra gimbal could be mounted in a dome painted with a sky background and used to simulate visual flight above a cloud layer. With an expanded altimeter range and the few extra instruments necessary to fly through the cloud layer to a landing, the whole aircraft regime could be simulated.

The extra gimbal could also be set up to simulate other flight tasks such as aerial refueling or carrier landings.

This project has provided the basic platform for a wide variety of research through flight simulation.

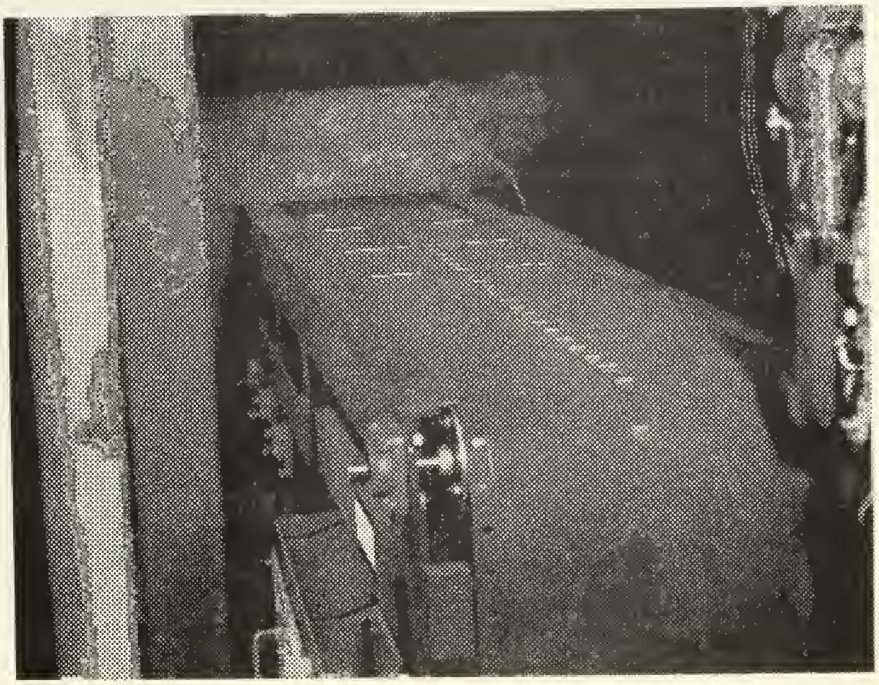


SMK-22

FIGURE 1

[illegible]

[illegible]

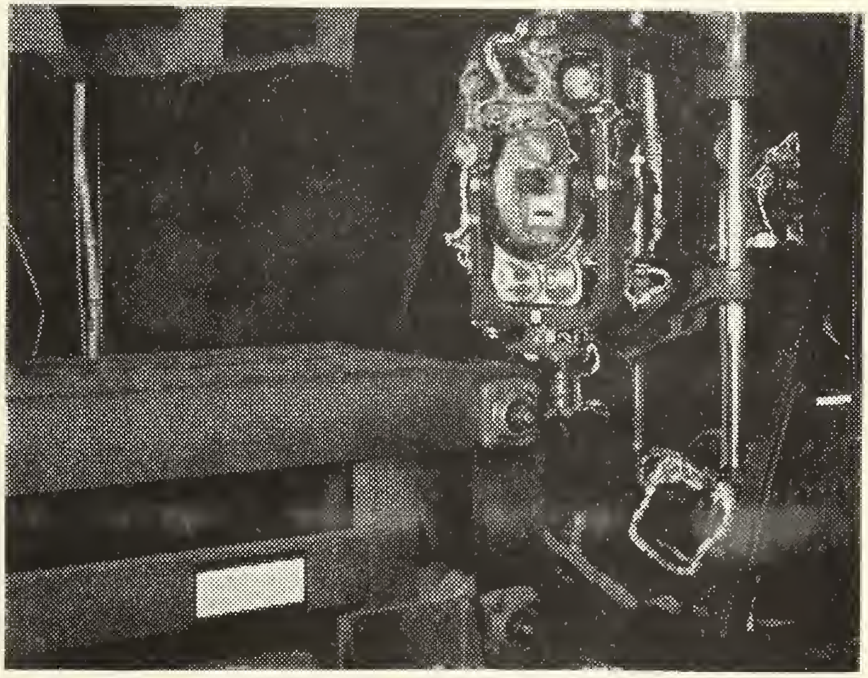


APPROACH LIGHTING

FIGURE 2

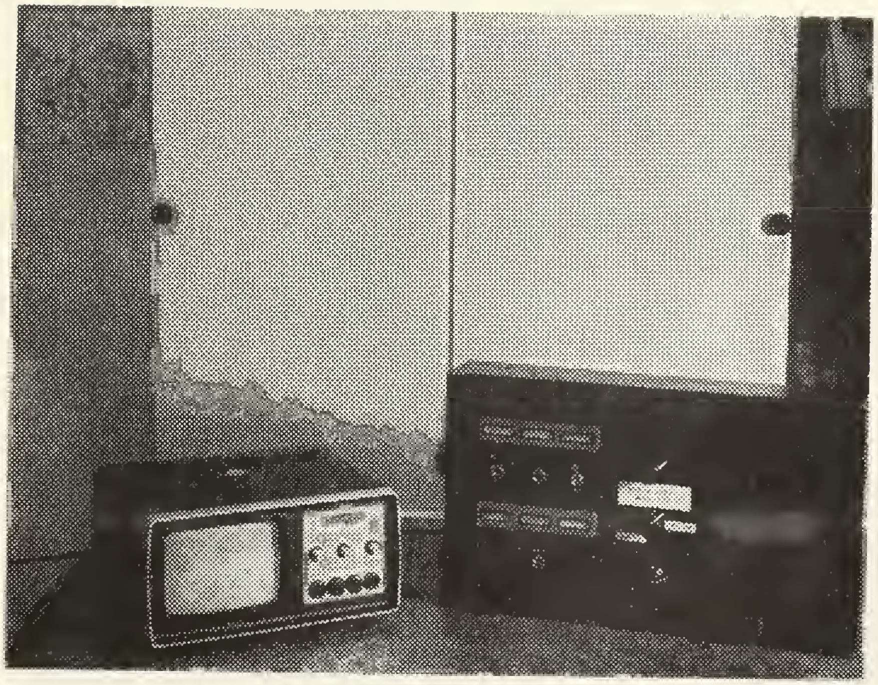
[illegible]

[illegible]



GIMBAL

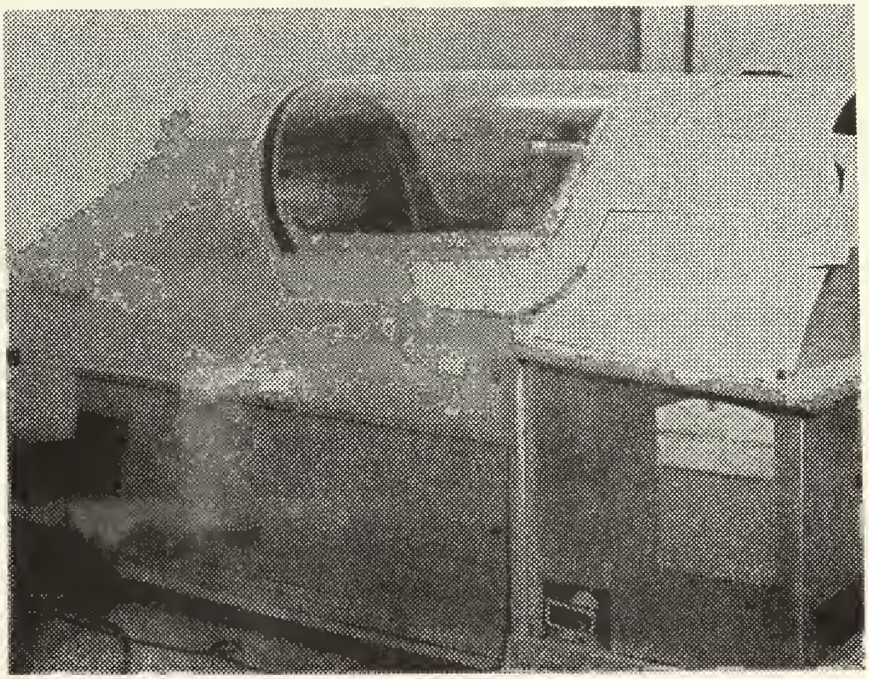
FIGURE 3



CONTROL CONSOLE AND TV MONITOR

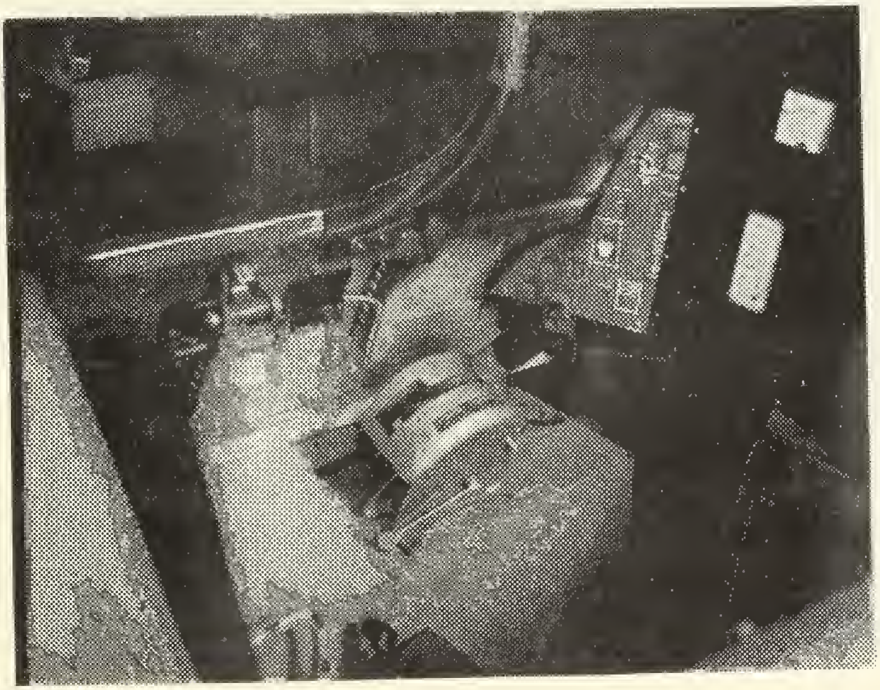
FIGURE 4

[illegible]



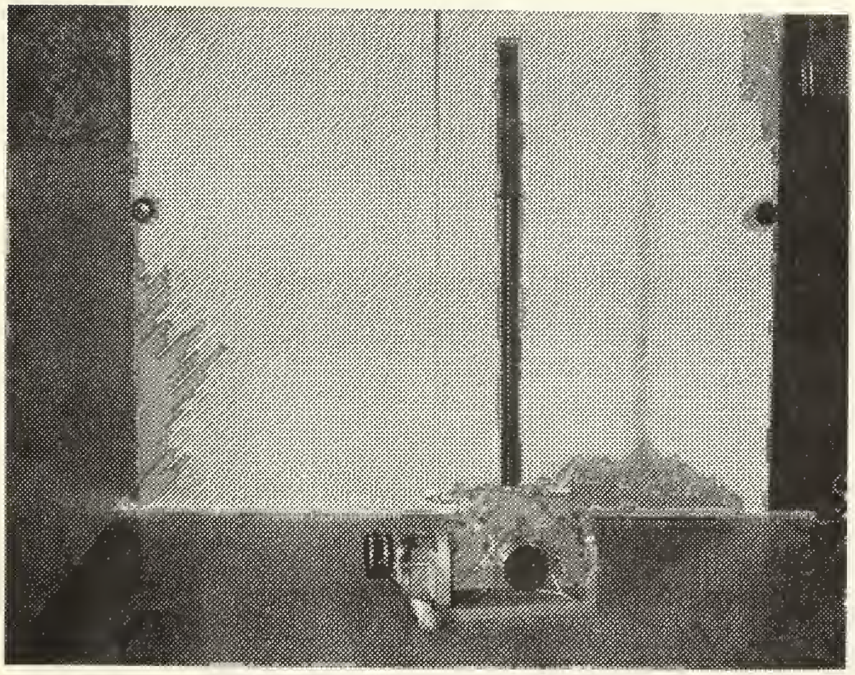
COCKPIT

FIGURE 5



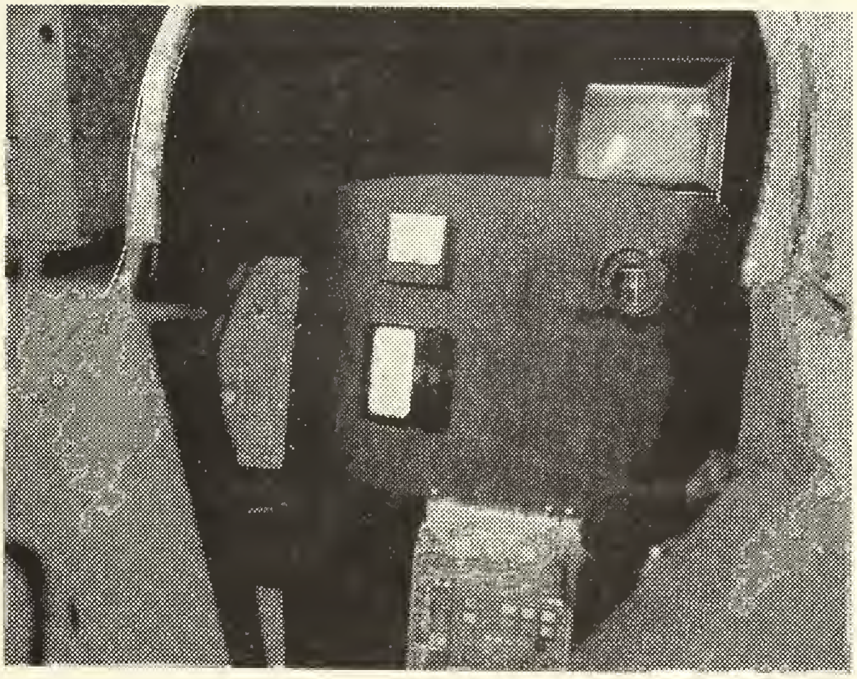
THROTTLE

FIGURE 6



STICK

FIGURE 7

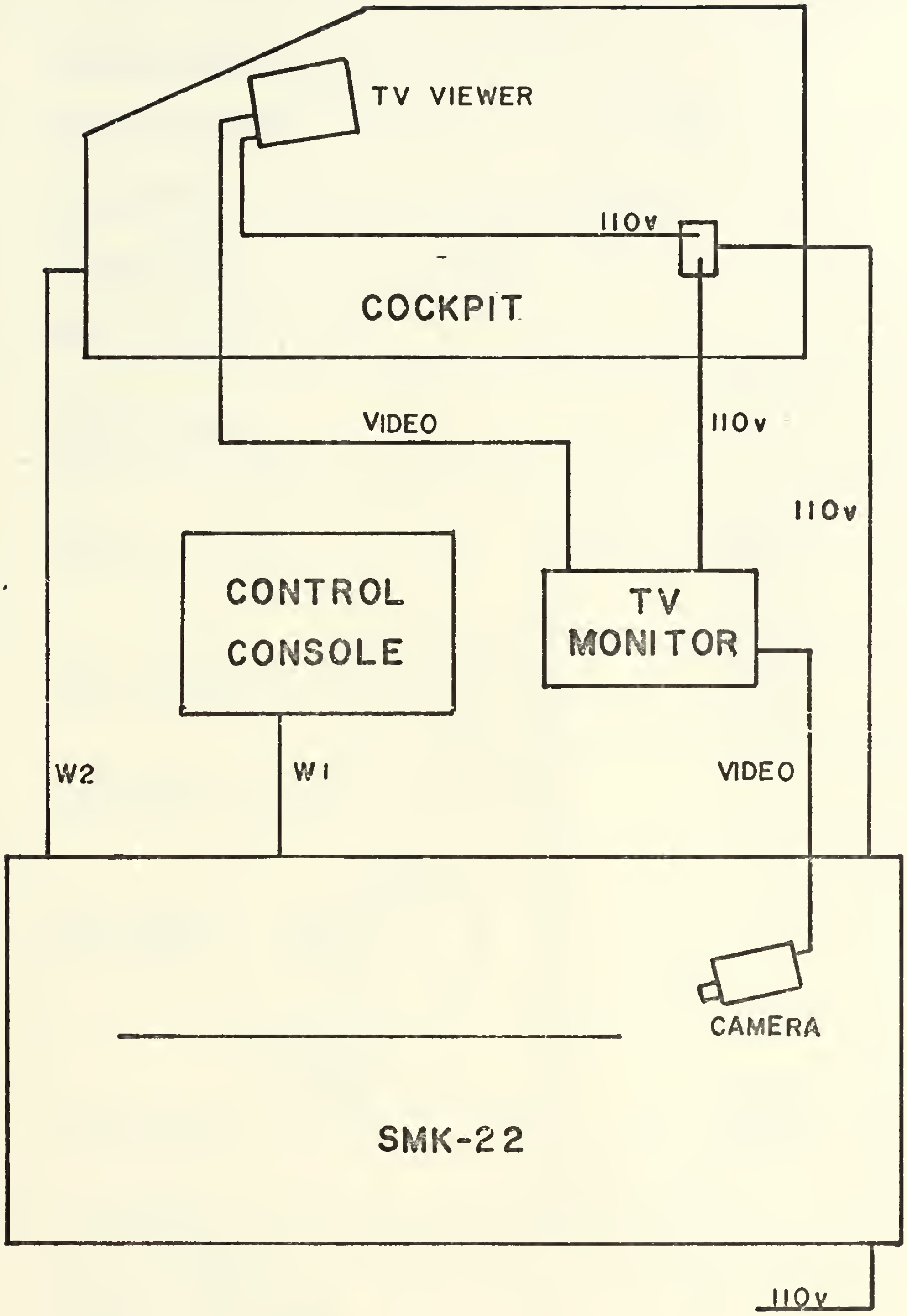


INSTRUMENT PANEL

FIGURE 8

[illegible]

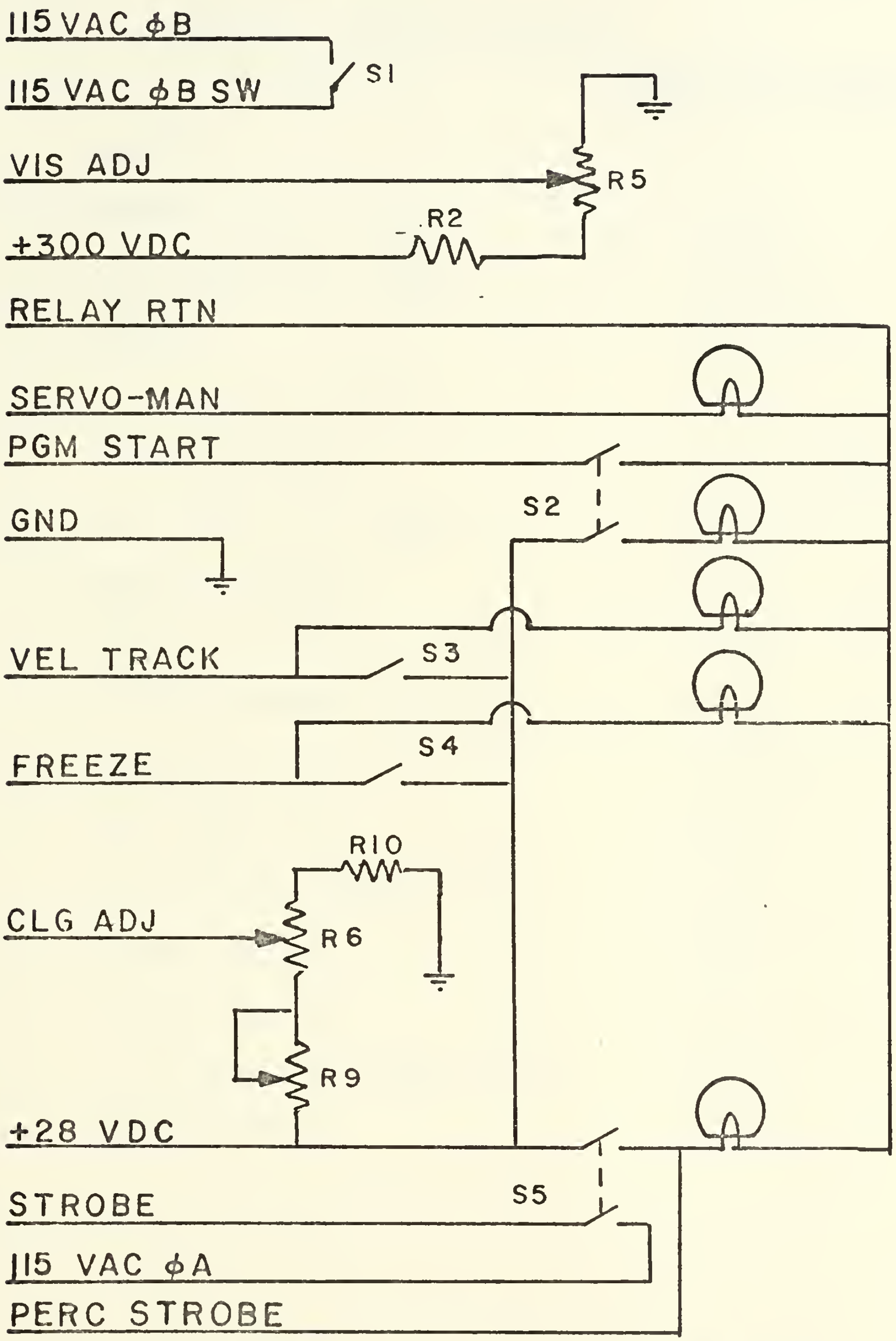
[illegible]



SYSTEM BLOCK DIAGRAM

FIGURE 9

CONTROL CONSOLE WIRING DIAGRAM



R2-120 KOHMS

R10-5.1 KOHMS

R5, R6, R9-50 KOHMS

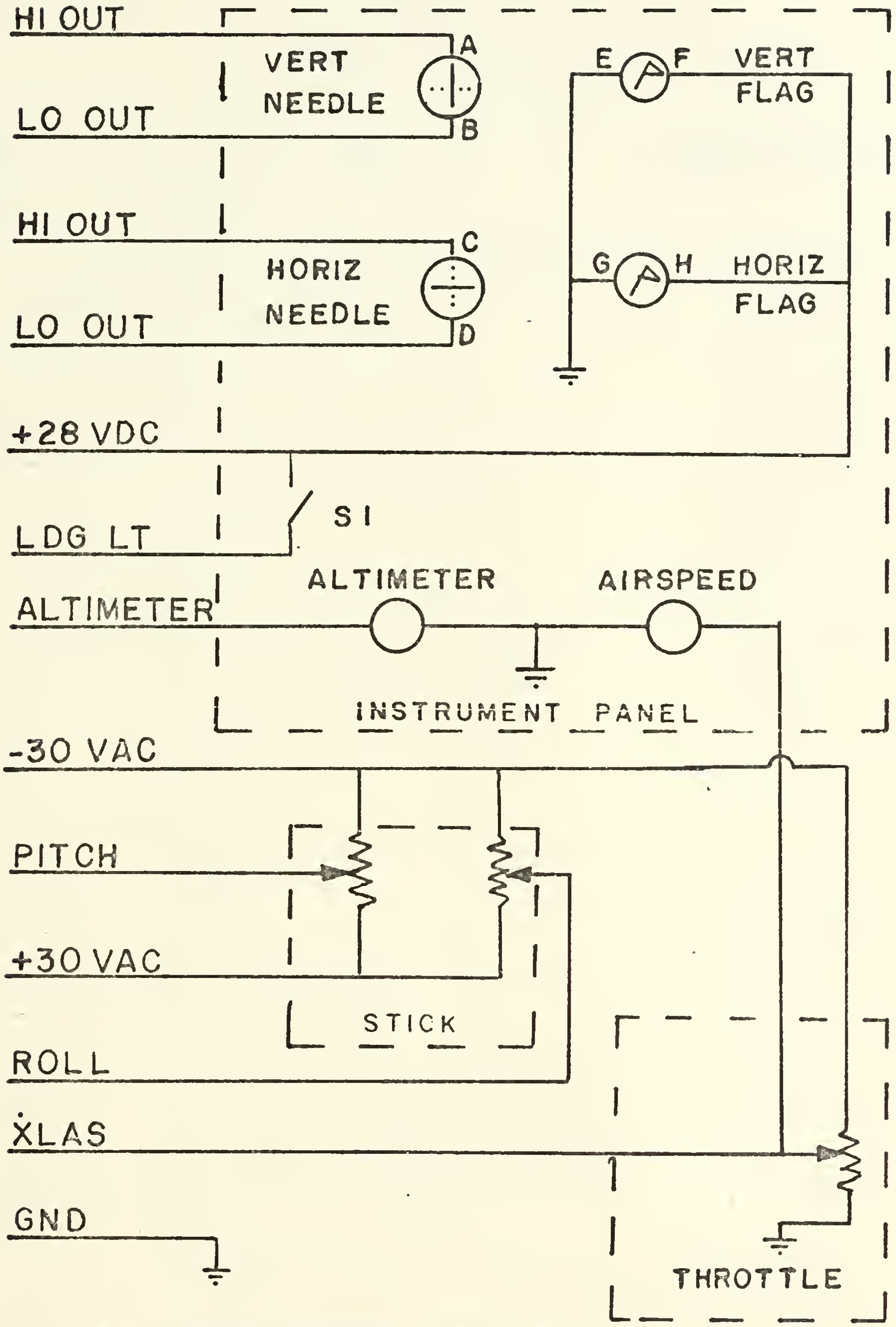
FIGURE 10

TABLE I

CONTROL CONSOLE CABLE W-1

WIRE	USE	SIMULATOR LOCATION
17	Spare	
18	Visibility Adjust	J3-K
19	115 volts a.c. phase B	TB3-12
26	Ground	TB4-12
27	Perceptual Strobe	J3-w
30	Velocity Track	K1-14 (Strobe)
32	115 volts a.c. phase A	TB3-10
34	Program Start	J3-d
35	Strobe lights	J3-e
40	Ceiling Adjust (not used)	J3-g
42	+300 volts d.c.	TB3-18
44	+28 volts d.c.	TB3-1
45	Servo-Manual Light	J3-Y
46	Freeze Switch	J5-d
47	Freeze Light	J3-U
48	115 volts a.c. phase B sw.	J3-W
49	Relay Return	TB3-6

COCKPIT WIRING DIAGRAM



ALL RESISTORS-5K OHMS

FIGURE 11

TABLE II

COCKPIT CABLE W-2

WIRE	USE	SIMULATOR LOCATION
A-D	Spares	
E	Relay Return (not used)	TB3-8
F	YLAS (not used)	TB2-13
G	XLAS	TB2-12
H	Landing Lights	K12-14
J	Altitude (not used)	TB1-12
K	Pitch	TB1-15
L	Roll	TB1-16
M	Vertical Needle Lo Out	TB2-4
N-P	Not Used	
R-T	Spares	
U	Altimeter	K4-3
V	Ground	TB4-11
W	+30 volts a.c.	TB4-2
X	-30 volts a.c.	TB4-4
Y	Horizontal Needle Hi Out	TB2-7
Z	Horizontal Needle Lo Out	TB2-8
a	Spare	
b	+28 volts d.c.	TB3-4
d	Vertical Needle Hi Out	TB2-3

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13. ABSTRACT

An F-105 Canopy/Seat Cockpit Trainer, Panasonic Television Monitor System, and an SMK-22 Visual Approach Simulator were interfaced to yield a low-cost, six-degree-of-freedom visual approach and landing simulation system for future research and classroom use. Stick and throttle outputs from the cockpit were made to operate all six degrees of freedom. The television monitor was mounted forward of the cockpit instrument panel to provide visual cues for approaches, landings, and take-offs. Cockpit instruments consist of airspeed, altimeter, and ID-249 ILS indicators.

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